A MAC scheme for avoiding inter-cluster collisions in wireless sensor networks

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***Abstract* — Recently, TDMA-based MAC protocols have been discussed in WSNs for their energy-efficient performance. In the use of TDMA-based MAC scheme, radios of sensors can be turned off during idle times in order to conserve energy. Clustering is an effective method for achieving high levels of energy efficiency and scalability, and is often combined with TDMA-based schemes to reduce the cost of idle listening.**

But, conventional TDMA protocols focus on intra-cluster communication MAC control. They don't consider collisions occurring among inter-clusters in developing architecture for WSNs that is extensible to hundreds of thousands of nodes.

This paper proposes a TDMA based MAC protocol for avoiding inter-cluster collisions which avoids collisions occurring among clusters.

***Keywords*—TDMA, inter-cluster collisions, time schedule, MAC protocols, wireless sensor networks**

I. Introduction

Communication in wireless sensor networks(WSN)s can be divided into several layers like most network communication. The MAC layer of those is described by a Medium Access control(MAC) protocol, which tries to ensure that no two nodes are interfered with each other's transmission, and deals with the situation when they do.

WSNs have an additional aspect: as sensor nodes are generally battery-operated, energy consumption is very important. When a receiver node receives more than one packet at the same time, these packets are called "collided packets" even then they coincide partially. All packets that cause the collision have to be discarded and the retransmissions of these packets are required which increase the energy consumption.

A fundamental barrier to achieve acceptable levels of performance in large scale WSNs is energy efficiency. Wireless sensors have limited energy supply and are usually deployed in environments where recharging is either impossible or too costly.

MAC schemes for WSNs are usually classified into two categories, contention based and contention-free. Contention-based scheme are widely applied to ad hoc wireless networks because of simplicity and a lack of synchronization requirements. Traditional contention-based schemes require sensor nodes to keep their radios on to receive possible incoming messages. Therefore, such schemes are not energy-efficient due to idle listening. Contention-free schemes are known as reservation-based or scheduling-based schemes. TDMA is an example of contention-free schemes. Radios can be turned off during idle times in order to conserve energy[1-3].

In addition, dividing the sensor network into non-overlapping groups of nodes, a process referred to as clustering, is an effective method for achieving high levels of energy efficiency and scalability. Clustering solutions are often combined with TDMA-based schemes to reduce the cost of idle listening[4-6].

The Bit Map Assisted MAC protocol(BMA) is an intra-cluster communication MAC protocols. The entire network is divided into non-overlapping clusters and LEACH[6] is used to divide into non-overlapping cluster. There is a cluster head in each cluster. Instead of transmitting the data to the base station directly, the sensors send their data to the cluster head and the cluster head relays the data to the global base station. Under this condition, the cluster head builds a TDMA schedule and broadcasts it to all nodes within the cluster. Each source node turns on its radio and sends its data to the cluster head over its allocated slot time, and keeps its radio off at all other times[1].

BMA focuses on intra-cluster communication MAC control. In developing the WSNs that is organized as hundreds of thousands of nodes, each cluster builds its own schedule independently. While one cluster member node turns on its radio and sends its data to the cluster head over its allocated slot time, members of other clusters may send their data to their cluster heads over their allocated slot time. In this case, there may be collisions among clusters due to building TDMA schedule of each cluster independently. To reduce this type of interference, each cluster communicates using different CDMA codes in LEACH. Thus, when a node is elected as a cluster head, it chooses randomly from a list of spreading codes and informs all the nodes in the cluster to transmit using this spreading code.

This paper approaches in the view of TDMA to solve the problem of multiple-access which may occur among the

Acknowledgement: This research was financially supported by the small & medium business administration.

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nodes of inter-clusters and proposes a TAC (TDMA based Avoiding Collisions) protocol which assigns a non-overlapping time schedule for a whole sensor area in a distributed manner.

The remainder of this paper is organized as follows. Section 2 introduces related researches. Section 3 introduces the TAC method. Finally, the conclusions are given in sections 4.

II. RELATE RESEARCH

BMA is an intra-cluster communication bit-map assisted MAC protocols for large scale cluster-based WSNs. The operation of BMA is divided into rounds, as in LEACH. Each round consists of a cluster setup phase and a steady-state phase.

The clusters are formed during the setup phase and the cluster formation algorithm is identical to the one described in LEACH[6].

The steady-state phase is divides into k sessions. The duration of each session is fixed. Each session consists of a contention period, a data transmission period and an idle period.

Assuming that there are N cluster member nodes within a cluster, and then the contention period consists of exactly N slots. During each contention period, all nodes keep their radio on. After each node is assigned a specific slot and transmits a 1-bit control message during its scheduled slot if it has data to transmit, the cluster head knows all the nodes that have data to transmit. The cluster head sets up a transmission schedule and broadcasts it for the source nodes.

After the contention period is complete, the system enters into the data transmission period. Each source node turns on its radio and sends its data to the cluster member over its allocated slot time, and keeps its radio off at all other times. All sources and non source nodes have their radios turned off during the idle periods.

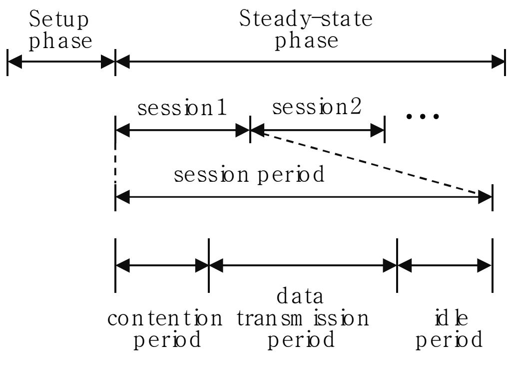


Figure 1. The operation of BMA

When a session finishes, the next session begins with a contention period and the same procedure is repeated. The cluster member collects the data from all the source nodes and then forwards the aggregated data to the base station directly or via a multi-hop path consisted of cluster head. After a predefined time, the system begins the next round and the whole process is repeated.

III. INTER-CLUSTER COLLISION AVOIDANCE

A. TAC

In developing the WSNs that is organized as hundreds of thousands of nodes, each cluster builds its own schedule independently. While one cluster member node turns on its radio and sends its data to the cluster member over its allocated slot time, members of other clusters may sends its data to their cluster member over their allocated slot time. In this case, there may be collisions among clusters due to building TDMA schedule of each cluster independently.

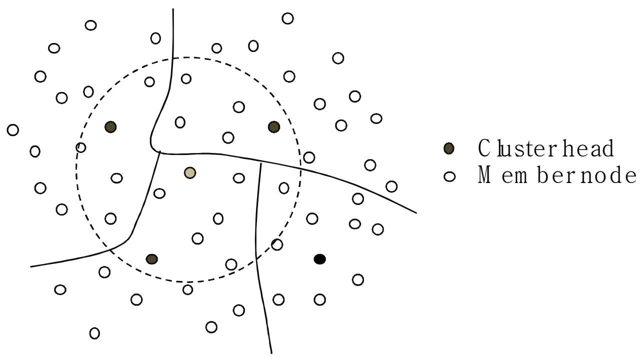


Figure 2. Clustering

Fig. 2 depicts how collisions occur, while members of each cluster send theirs data to the cluster member over theirs allocated slot time. While the gray node which is the member node of a cluster sends its data to the cluster member, there can occur collisions with the member nodes of adjacent clusters, because the transmission range of the gray node passes over its cluster.

To solve this problem in the view of TDMA, each session period is divided into four non-overlapping parts in fig. 3. It is important that a different group period has to be assigned among adjacent clusters.

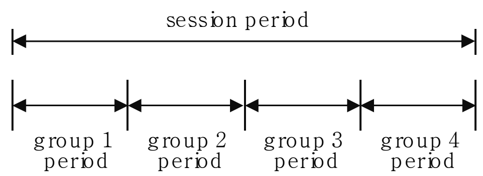
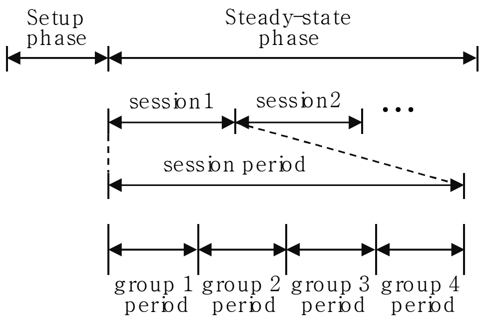
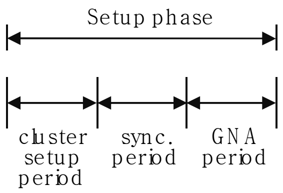


Figure 3. Session period

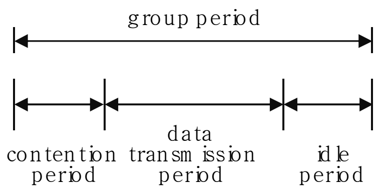
The operation of TAC is divided into rounds, as in LEACH. Each round consists of a setup phase and a steady state phase. A complete round is depicted in fig. 4.



(a) TAC round



(b) Setup phase



(c) Each group period

Figure 4. The operation of TAC

B. SETUP PHASE

A setup phase consists of a cluster setup period, a synchronization period and a GNA (Group Number Allocation) period. The clusters are formed during the cluster setup phase and the cluster formation algorithm is identical to the one described in LEACH.

To form clusters in LEACH, each node must dicide whether it could become a cluster head, based on the suggested percentage of cluster heads for the network. Elected cluster members broadcast a cluster head advertisement message to all other nodes claiming to be the new cluster members by using CSMA. Next, the cluster member nodes decide the cluster to which it will belong for this round, based on the received signal strength of the advertisement.

The synchronization process is needed among clusters to set non-overlapping time schedule among clusters. We follows the synchronisation process that is proposed in [7]. The network is composed of cluster head, cluster member, CHR(Cluster Head Reference), which is the reference clock node of cluster heads. Cluster heads have a connection with the CHR directly or indirectly and are synchronized with the cluster head reference.

During the GNA period, the group number(GN) is allocated to each cluster. The non-overlapping time period of each cluster is determined based on the GN allocated in this period. It is important that a different group period has to be assigned among adjacent clusters to avoid inter-cluster collisions.

In a cellular network employing frequency reuse accross different cells, the available bandwidth is divided into three non-overlapping parts which are assigned to three neighboring cells in fig. 5[8].

Assumming that the GN is allocated manually or ideally by a central control center, it is enough that the whole session period is divided into three non-overlapping parts which can be assigned to three neighboring clusters in WSNs.

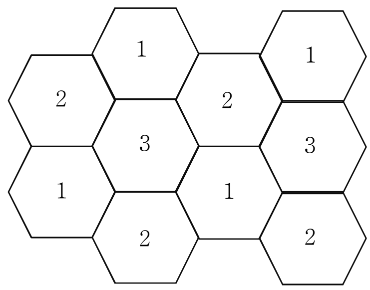


Figure 5. Hexagonal system layout and ideal periods planning for clusters

To allocate non-overlapping GNs with neghbor clusters dynamically, we introduce a GNA algorithm.

First, CHR sets number 1 as GN and sends GNA message including its own GN. A neighbor cluster head which receives the GNA message sets its own GN and broadcasts the GNA message including its own GN. The GN is selected in the range 1~4 except GNs in the received GNA messages. After a cluster head determines its own GN, it receives the GNA message which includes the same GN, then it sets again its own GN and broadcasts the GNA message.

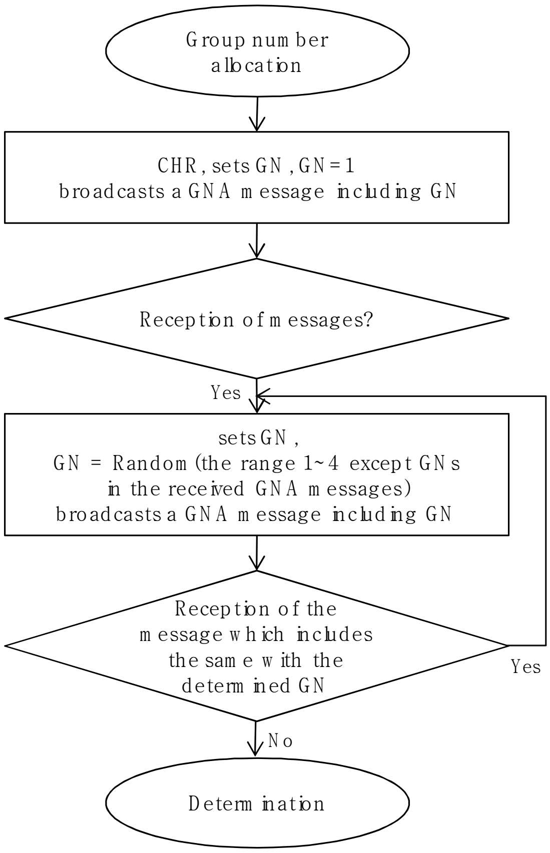


Figure 6. GNA algorithm

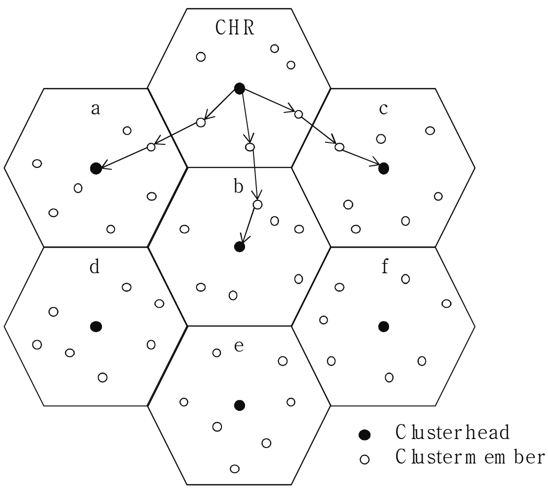


Figure 7. A GNA messages transmission model

The GNA messages is relayed by cluster members to neighbor cluster heads in fig. 7.

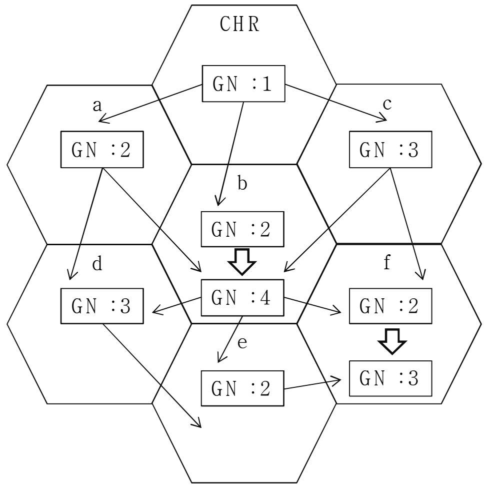


Figure 8. An example of GNA process

In fig. 8, CHR sets number 1 as GN and sends a GNA message including GN to neighbor cluster heads. The cluster head of cluster ***a***, ***b***, ***c*** set 2, 2, 3 as GN and broadcasts a GNA message including GN. After the cluster head of cluster ***b*** determines its own GN, it receives the GNA message from the cluster head of cluster ***a*** and the messages includes the same GN with its own GN. The cluster head of cluster b changes GN as a number 4 which is selected in the range 1~4 except 1, 2. The group period for each cluster is determined based on its own GN.

C. STEADY-STATE PHASE

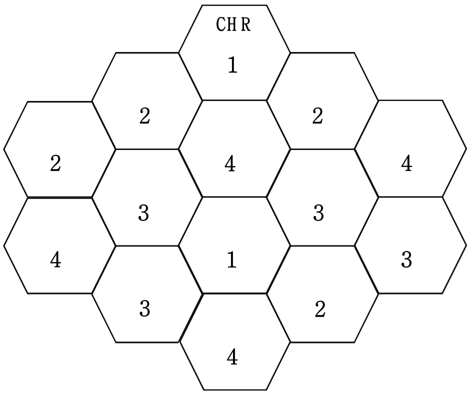
The steady-state phase is divided into k sessions and each session consists of four group periods in fig.4(a). Clusters are synchronized and the duration of each group period is fixed. The cluster heads start their own time schedule at the group period based on their own non-overlapping GN. The operation within group period is exactly as in BMA.

IV. EXPERIMENTS

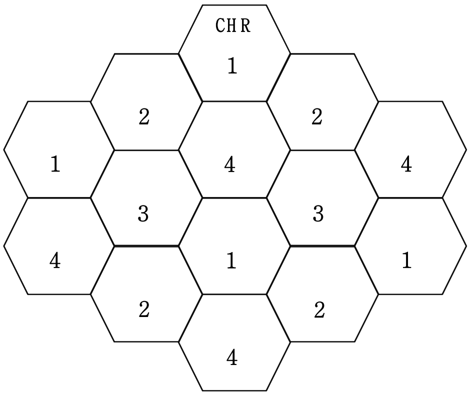
We experiment to verify the performance of the GNA algorithm through simulations. The GNA algorithm is implemented in C. Experimental MANET consists of 14 hexagonal clusters in fig. 9. From 100 simulations times, we can obtain 100% non-overlapping group number about each cluster.

Fig. 9(a) shows that the same GNs with adjacent clusters are allocated to several clusters and fig. 9(b) shows the result of reallocation.

The reallocation rate is determined by dividing by the number of clusters to the number of reallocation. In the result of fig. 9(b), the reallocation rate is 0.21.



(a) The result of first GN allocation



(b) The result of GN re-allocation

Figure 9. MANET area which consists of 14 hexagonal clusters

V. CONCLUSIONS

We propose a TDMA based MAC protocol for avoiding inter-cluster collisions. To avoiding inter-cluster collisions, the whole session period is divided into four non-overlapping parts. Each group period is determined on based the GN of each cluster. The GNA algorithm is proposed to allocate the GN to each cluster and designed to allocate non-overlap the GN which is different with the GN of adjacent clusters. The results of simulation show the clearness of the proposed algorithm and our proposed algorithm is particularly simple and straightforward. Our future plan is to implement the practical protocols and analysis to performance.

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